SCIENCE FOR GLASS PRODUCTION

UDC 666.053.2:621.373.826

CHOICE OF THE OPTIMAL LASER FOR CONTROLLED THERMAL SEPARATION OF OXIDE GLASSES

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Translated from *Steklo i Keramika*, No. 6, pp. 3 – 6, June, 2007.

The use of mid-IR range lasers (3 – 7 μm) for controlled laser thermal separation of oxide classes is analyzed. It is shown that CO lasers (5.1 – 6.2 μm) greatly improve the quality of this technology.

The method of controlled laser thermal separation of oxide glasses, which was developed in the 1980s [1], is now widely used for precise separation of glass for display panels, including liquid-crystal screens and plasma panels. The facts that the corresponding equipment is being manufactured and there are many publications attest to this [1 – 6]. The most important advantages of this cutting method are its high rate, high accuracy in sized cutting, low consumption of energy as compared with other known cutting methods, high cleanliness because the separation process is waste-free, and zero width of the cut.

A salient feature of the method of controlled laser thermal separation is that the glass separates not as a result of vaporization of the glass along the cutting line (as happens, for example, in laser scribing) but rather because when the laser radiation heats the material and the heated zone is cooled down by applying coolant tension stresses are generated and a separation crack is formed [1 – 5].

For CO_2 lasers the mechanism of controlled laser thermal separation is as follows. When laser radiation to which a glass is opaque is used to irradiate a glass surface high compression stresses appear in the outer layers of the glass. However, these stresses do not cause the glass to break. This is because the compression strength of the glass is several-fold greater than the tension or bending strength. The surface layers of the glass at the site where the heated section exits the laser interaction zone start to cool down. When coolant is applied, sharp local cooling of the surface of the glass along the separation line occurs immediately behind the laser beam. The temperature gradient produced gives rise in the surface layers to tension stresses which exceed the ultimate strength and lead to the formation of microcracks that penetrate deep into the glass in the heated interior layers which are under a compression stress. Thus, a microcrack appears in the glass at the boundary between the heated and cooled zones, i.e., at the location of the maximum temperature gradient. The depth of this microcrack is determined by the distribution of the thermoelastic stresses which depend on the parameters of the glass and the laser beam.

This cutting method developed in two directions.

The first one is a surface microcrack produced by CO_2 laser radiation (10.6 μm). Such radiation is absorbed in oxide glasses to depths no more than 50 – 100 μm [1]. Consequently, the microcrack produced does not exceed $\delta \sim 5$ – 100 μm in size but the rate of growth of this crack can increase substantially — up to 2000 mm/sec. An additional operation is used to separate a glass article through its entire thickness. Ordinarily, this operation is mechanical breaking. The maximum thickness of the glass being separated with CO_2 laser radiation, as a rule, does not exceed $t \sim 5$ mm (through thermal separation of glass can be accomplished by repeatedly irradiating the microcrack with CO_2 laser radiation, but then the cutting rates are low). Heating of the glass surface is necessary condition, which a CO_2 laser beam with wavelength 10.6 μm satisfies. In contrast to volume heating, for through thermal separation of glass with 1.06 μm Nd laser radiation, surface heating together with the use of a coolant to cool the heated zone gives 100 times higher rates of thermal separation.

The second direction is a volume (through) microcrack produced by 1.06 μm Nd laser radiation. It is well known that oxide glasses have low absorption for Nd laser radiation

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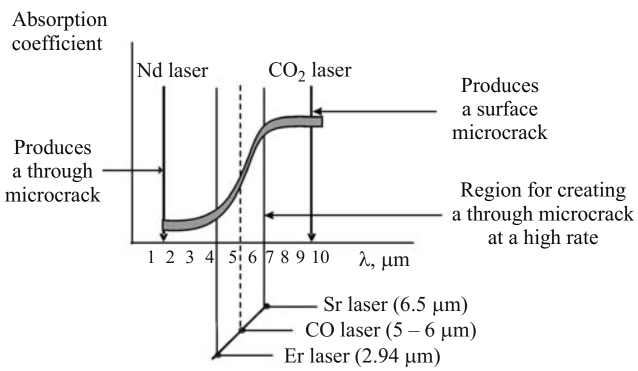

Fig. 1. Absorption spectra of oxide glasses and laser radiation for thermal separation of these glasses.

[1, 2, 7]. However, with high laser power ($P \gg 100$ W, 800 W is better) even this absorption will be sufficient to produce thermal stresses which lead to the formation of a through microcrack which separates glass articles. A salient feature of this method of controlled laser thermal separation is that it makes possible through separation of glass with large thickness — up to $t \sim 30$ mm, but with very low cutting rates — up to 100 mm/sec. However, not all types of glasses can be worked with such a laser. High-purity glasses whose absorption of Nd laser radiation is less than 0.1 – 1% are not amenable to thermal separation.

The main application of the controlled laser thermal separation technology is sized machining of glass for displays where through separation of glass with thickness $t \sim 0.6$ – 0.8 mm to within 5 – 20 μm at 500 mm/sec is required. However, the lasers mentioned above do not solve this problem. Consequently, it is important to search for new lasers for thermal separation of glass with such parameters.

A preliminary analysis has shown that the optimal laser is one whose radiation spectrum lies in the translucence range of glasses (2 – 7 μm) and whose power level is at least 100 W (Fig. 1). Several types of lasers emit in this range: solid-state Er lasers (2.94 μm), repetitive-pulse Sr-vapor lasers (1.0, 3.0, and 6.4 μm), and continuous-wave CO gas lasers (5.1 – 6.2 μm).

However, the power of a solid-state repetitive-pulse Er laser is low ($P_{av} < 10$ W), making it unsuitable for this technology. The strontium-vapor laser is a unique source of radiation and emits at several wavelengths simultaneously: 1.0, 3.0, and 6.4 μm. Most of the power is concentrated near 6.4 μm. However, the laser developed at Tomsk State University by A. P. Soldatov's team has low power (20 W) and is a quite complicated experimental setup. Although, the present authors obtained good results for thermal separation of glass, confirming that this technology requires a laser operating in the range 5 – 6 μm.

The optimal laser is a continuous-wave CO laser (5.1 – 6.2 μm). Several types of such lasers are produced domestically (Federal State Unified Enterprise Scientific – Industrial Association "ISTOK"). The authors of the present paper used a CO-laser based on an OLGN-711 emitter upgraded

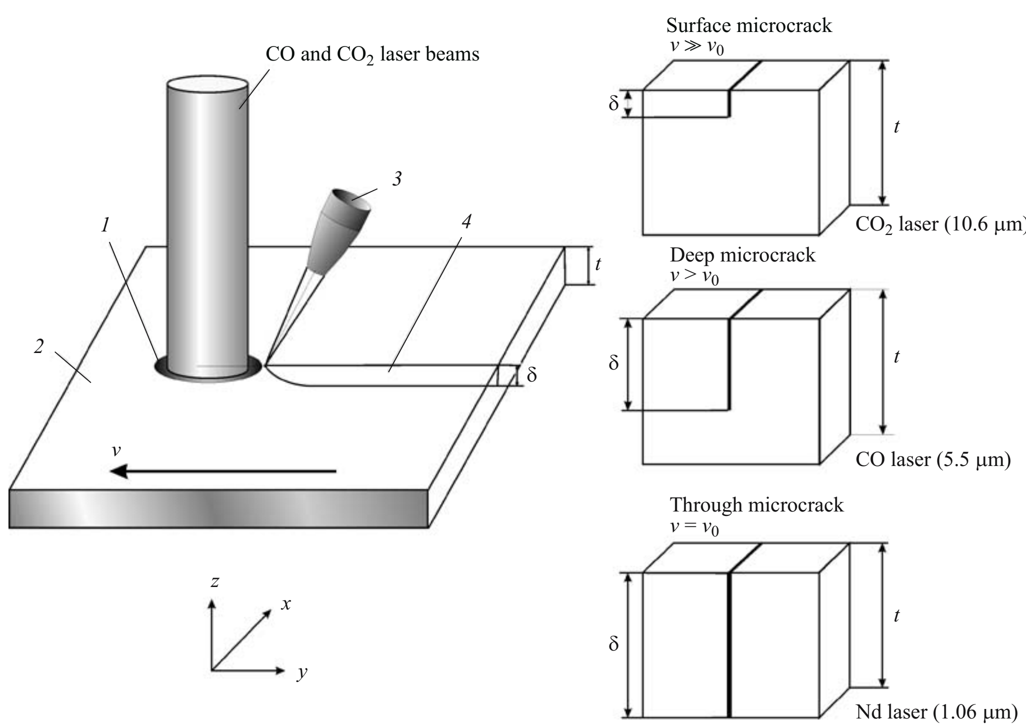

Fig. 2. Scheme of a setup for controlled laser thermal separation of glasses: *1*) heating zone; *2*) glass; *3*) cooling nozzle (air, N_2); *4*) microcrack; *v*) velocity of the glass.

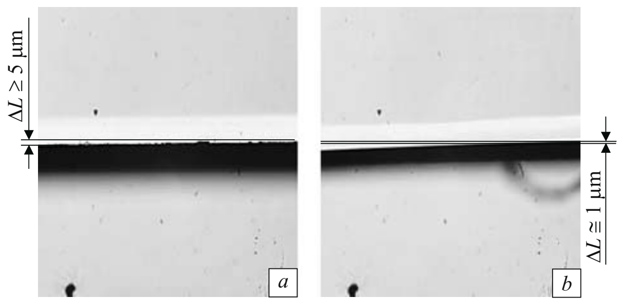

Fig. 3. Photograph of glass fragments obtained with CO_2 (*a*) and CO (*b*) laser radiation.

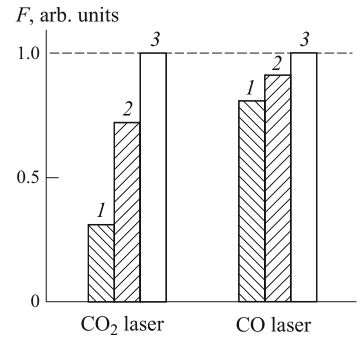

Fig. 4. Histograms of the strength *F* of glass ships obtained by thermal separation of 1-mm thick glass by CO_2- (10.6 μm) and CO- (5 – 6 μm) laser radiation: *1*, *2*, and *3*) maximum, average, and minimum values.

for periodic replacement of the radiating gas mixture, which provided a stable 100-W laser [8].

The objective of our work is to investigate the use of CO lasers for cutting glass by the thermal separation method as compared with the same method using CO_2 and Nd lasers.

It is of interest to use CO lasers for controlled thermal separation technology because their radiation spectrum ($\lambda = 5.1 – 6.2$ μm) lies near the transmission band limit of many glasses and such radiation effectively penetrates glass material to depths 200 – 500 μm.

We developed the setup shown in Fig. 2 to investigate thermal separation regimes. The main components are CO_2 and CO lasers, $X – Y$ motors with air suspension, and utility systems.

Thermomechanical calculations of the process of thermal separation of glass using CO laser radiation were performed. The distributions of the tension-stress fields, acting perpendicular to the separation plane of the samples irradiated with CO_2 and CO lasers, respectively, were obtained. The calculations showed the following.

In the first place, the spatial distribution of the zones of maximum compression stresses in the volume of the material, which stop the propagation of a microcrack and determine its depth, is characterized by greater depth in the sample being worked with CO laser radiation ($\delta = 200$ μm for a CO_2 laser and 400 μm for a CO laser). The form of the distribution of the thermoelastic fields of the compression stress zones gives deeper development of a microcrack for a CO laser than for a CO_2 laser.

In the second place, the maximum temperatures are approximately 20% lower for a CO laser with the same laser radiation power and the same beam shape. The tension stresses in both cases are approximately the same, which makes it possible to increase the power of the CO laser radiation. This will increase the tension stresses generated in the coolant application zone, increase the probability of microcrack initiation, and make the process more stable.

In the third place, volume heating in the regime of through thermal separation or final laser separation can decrease the influence of edge effects, since the tension stresses ahead of the laser beam are smaller for a CO laser than a CO_2 laser. As result, uncontrollable crack development near the boundary of a sample starts later, so that the edge effect is weaker.

The experimental work performed with the setup using CO_2 and CO lasers confirmed the computed behavior of a microcrack during controlled thermal separation.

The same type of glass (thickness $t \sim 1$ mm) and the same CO- and CO_2-laser power (100 W) were used. The work on obtaining the maximum through thermal separation rate for millimeter-thick glass using the radiation from these lasers at the same power was performed first. The CO laser gave a 2 – 3 times higher separation rate than the CO_2 laser.

The effect of the type of emitter on the technological process was compared using the following parameters: the surface quality of a glass fragment after separation (strength, microscopic nonuniformity) and the maximum thermal separation rate. The experimental work showed that the glass fragments obtained with a CO laser are of higher quality (Fig. 3). Comparative mechanical tests performed on the glass samples obtained showed that glass articles obtained with a CO laser had a higher mechanical strength (Fig. 4). This confirms that CO laser radiation is the main tool for laser controlled thermal separation for producing flat LCD, PDP, and other types of display panels.

In summary, our work on controlled laser thermal separation with a CO laser established the following:

a high through thermal separation rate is obtained for glass with thickness 0.7 – 1.0;

the through thermal separation rate for glass exceeds 300 mm/sec, which is much higher than that obtained with CO_2 and Nd lasers;

the glass fragments obtained have a minimal number of microinhomogeneities and higher strength than the glass samples obtained with a CO_2 laser.

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